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DEPARTMENT OF THE AIR FORCE
HEADQUARTERS AERONAUTICAL SYSTEMS DIVISION (AFSC)
WRIGHT-PATTERSON AIR FORCE BASE, OHIO 45433

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TECHNICAL MEMORANDUM WCLD 58-12

OPTIMAL ELASTIC CHARACTERISTICS OF EJECTION SEAT CUSHIONS FOR SAFETY AND COMFORT

Prepared by
Aero Medical Laboratory

17 February 1958

Project No. 7215
Task No. 71724

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Technical Memorandum
WCLD 58-12
17 February 1958

Aero Medical Laboratory
Directorate of Laboratories
Project No. 7215
Task No. 71724

OPTIMAL ELASTIC CHARACTERISTICS OF EJECTION SEAT CUSHIONS FOR SAFETY AND COMFORT

A. PURPOSE:

~~To~~ The report summarizes available data pertaining to those characteristics of aircraft seat cushions which modify the force acting on the seat occupant during headward acceleration (ejection and impact landing). This data should help to establish optimal seat cushion characteristics and to design a standard program for the evaluation of new cushions. ( )

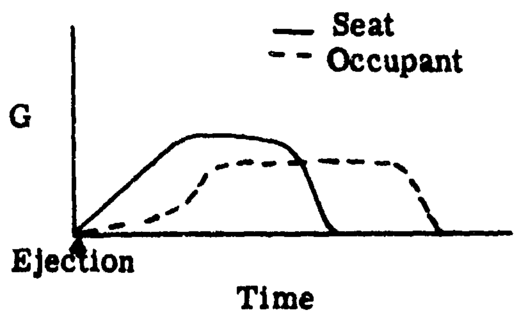
B. FACTUAL DATA:

1. The first ejection seats were developed by the Luftwaffe during World War II. Early ejections caused a large number of compression fractures of the spine. Investigations indicated that the pilots were exposed to larger G forces than the ejection seats because of a thick seat cushion. As a result of these investigations, Luftwaffe ejection seat cushions were of a maximal thickness of 40 mm., as reported in German Aviation Medicine in World War II, Vol. I.

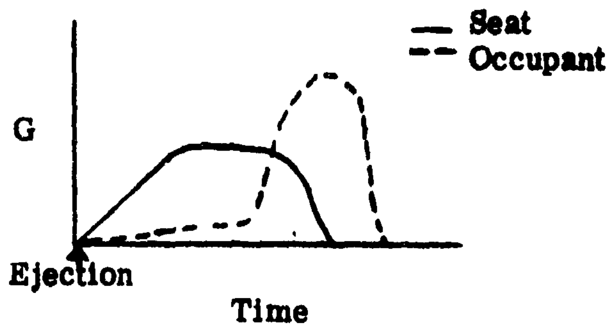
2. In early studies at WADC, the acceleration of a rigid dummy was measured during simulated catapult ejections, with and without an air-filled cushion between the seat and the dummy. Mean peak acceleration of the dummy without a cushion was 10.8G. With an air-filled cushion, the mean peak acceleration was 13.5G, as reported in AMC Memorandum Report No. TSEAC-11-45341-1-2, 9 August 1946. Tests on human subjects with medium density foam rubber cushions revealed peak accelerations of 11G to 33G. These values were consistently

higher than the accelerations of the seat at the same ejection, as reported by H. E. Savely, in AMC Engineering Division Memo Report No. TSEAA 695-66-C, October 1946.

3. The effect on the acceleration of seats and occupants, at ejection, of varying the thickness of medium density foam rubber cushions was also studied at WADC and reported by E. G. Sperry, Captain, USAF, in WADC Project Engineering Book for 1951. Figure 2, Appendix II, presents the data from these studies. Because "medium density" foam rubber is of variable consistency, specific points on this graph can be considered representative only within wide limits. However, the general trend of increasing G and rate of onset of G acting on the seat occupant, as cushion thickness is increased, is well demonstrated. Cushions of the compression resistance used in this study which exceed 3.5 inches in thickness amplify the G force acting on the seat occupant, relative to that acting on the seat. Any foam rubber cushion increases the maximum rate of onset of the G force. The maximum G acting on the occupant is decreased when a 1-inch to 3-inch cushion is used. G-profiles of the seat and occupant might be diagrammed for the purpose of illustration, as in Figure 1, below.



Diagrammatic G-Time Course during ejection, on 1-inch medium density foam rubber cushions. The occupant accelerates more rapidly but reaches a lower G load than the seat.



Diagrammatic G-Time Course during ejection, on 4-inch medium density foam rubber cushions. The occupant accelerates faster and reaches a higher G load than the seat.

4. The most extensive studies of acceleration patterns during ejection with various seat cushions have been reported by Wing Commander Latham of the RAF Institute of Aviation Medicine in "A Study in Body Ballistics", Proc. Royal

Soc. B 147:121, 1957. Acceleration of the seat and the subject (hip) were measured simultaneously during a long series of mock ejections. A peak of 20G was reached within graded time intervals between 0.01 and 0.2 seconds. Cushions of Sorbo rubber (3 inches thick) were compared with cushions of multiprene (2 inches thick). The Sorbo rubber cushion increased the G force acting on the seat occupant, relative to that acting on the seat by the factor of 1.26 to 1.85, while the multiprene cushion increased this force by a factor of 1.06 to 1.63. The jolt* experienced by the subject was 30% greater with the Sorbo rubber cushion. As a result of these studies, the RAF has replaced all foam rubber ejection seat cushions with cushions of plastic (multiprene or duoprene). RAF efforts to develop a static or dynamic mechanical test of cushion functions have not been successful. All new cushions are therefore evaluated by experienced subjects during catapult ejections, according to personal communication from Wing Commander Latham, Institute of Aviation Medicine, Farnborough, England, 1957.

5. There are a number of USAF accident reports in which the seat cushion (A-5) of small compression resistance and considerable thickness is implicated as the sole or a contributing factor in causing compression fractures of the spine, according to personal communication from Franklin D. Van Wart, Captain, USAF, and Nina K. Morrison, Captain, USAF, both of the Aero Medical Laboratory, WADC, and according to Directorate of Flight Safety Research Publication 2-57, entitled "The Problem of Back Fractures During Ejection from USAF Aircraft", by J. Davies, dated 7 January 1957. Because of the number of additional factors (harness, initial and final body position, magnitude, duration, and direction of the force, strength of the specific vertebra, etc.) in any specific instance, it is actually possible only to conclude that a specific cushion increases the likelihood of a vertebral fracture. It is not generally possible to establish with precision the relative importance of any one factor in producing an accidental compression fracture.

6. At one time it was believed that foam rubber cushions had to be thick in order to be comfortable. Foam rubber cushions developed more recently (MC-1 and MC-2) have met laboratory and operational comfort requirements and are thin enough to minimize the danger at ejection and/or impact landing. Studies at the Aero Medical Laboratory, USAF, are in agreement with those of the RAF (4 above) in suggesting that a further improvement in both safety and comfort would be effected by use of a suitable plastic (e.g., polyurethane) seat cushion. This is again in accordance with communication from Captain Van Wart and Captain Morrison.

*First derivative of the hip acceleration with respect to time.

7. Discussion

a. Ejection seat cushions of low compression resistance and/or great thickness may significantly magnify the force acting on the seat occupant during headward acceleration.

b. During any specific headward acceleration, this magnification of force increases the likelihood of injury, e.g., compression fracture of a vertebra.

c. The standard MC-1 and MC-2 cushions (medium density foam rubber) are not thick enough to constitute such a hazard. The limited standard A-5 cushion may magnify the force acting on the subject during headward acceleration.

d. The best available cushions are made of plastic, with a compression resistance high enough to safely permit a thickness adequate for comfort.

e. Retrospective analysis of accidents can rarely, if ever, establish with certainty the relative importance of the seat cushion in causing a specific vertebral injury. For this reason, data obtained by the analysis of accident reports should not be a major consideration in cushion selection.

C. CONCLUSIONS:

1. Ejection seat cushions should be limited to those having a high compression resistance and/or little thickness, to augment safety and comfort of the seat occupant.

2. The current limited standard cushions which violate the preceding characteristics (A-5) should be withdrawn from USAF aircraft having ejection seats.

3. A standardized procedure should be established at the Aero Medical Laboratory for the evaluation of the safety and comfort of ejection seat cushions as a prerequisite to standardization of these items. Dinghies, parachutes, and survival kits which are used as cushions or under cushions should also be so evaluated.

4. For the present, the ultimate safety test for each cushion design should include a series of test ejections with human subjects.

5. Further studies should be conducted to define precisely the critical cushion characteristics with the aim of substituting a mechanical test of the cushion for the more expensive testing on human subjects.

6. Current foam rubber seat cushions should be replaced with plastic cushions, if further tests verify their superiority for safety and comfort.

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PUBLICATION REVIEW

This report has been reviewed and is approved.

JACK BOLLERUD
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APPENDIX I

BACKGROUND DATA:

1. When a large headward force is abruptly applied to an aircraft seat (ejection or impact landing), the elastic properties of the seat cushion influence the relative magnitude and duration of the force acting on the seat occupant. The critical properties of the seat cushion are compression resistance and thickness. An optimal cushion functions as an efficient shock absorber to decrease the force acting on the seat occupant, relative to that acting on the seat. This is accomplished by gradual transmission of the force from the seat to the occupant as the cushion is being compressed. In this way, the seat occupant is accelerated less rapidly than the seat. The occupant is accelerated over a longer time period, so that the final velocities of seat and occupant are identical.

2. In contrast, with a thick cushion of low compression resistance, compression of the cushion consumes an appreciable time interval during which force is acting on the seat, but not on the seat occupant. As a result, the occupant, for an instant, is accelerated more rapidly than the seat. In common terminology, this is the phenomenon of "bottoming". The accelerations of the seat which are encountered at ejection and, upon impact landing, approach the compression tolerance of vertebrae.* For this reason, a relative increase in the acceleration of the seat occupant is not desirable.

3. It is recognized that the characteristics of the seat cushion are but one of many factors determining the likelihood or the extent of injury in any instance, as discussed in "Theoretical Investigations of Dynamic Response of Man to High Vertical Accelerations", by J. L. Hess and C. F. Lombard in the Journal of Aviation Medicine 29:66, 1958, and by J. R. Poppen in "Support of Upper Body Against Accelerative Forces in Aircraft", Journal of Aviation Medicine 29:76, 1958.

*The 12th thoracic vertebra carries approximately 50% of the total body weight on an area of approximately 20 cm^2. In a 180-pound man, this amounts to 4.5 lb/cm^2 at 1G. With a headward force of 20G acting from the seat, the pressure on this vertebra would be 4.5 x 20 or 90 lb/cm^2. Compression tests on fresh vertebrae have indicated that fractures occur at about 100 lb/cm^2, as reported in German Aviation Medicine in World War II, Vol. I. Flexion of the spine decreases the weight-bearing surface area of the vertebrae by a factor of 2 to 5, or more. In the example above, if the spine were flexed, the pressure would be 180 to 450+ lb/cm^2.

APPENDIX II

Figure 2